DOI: https://doi.org/10.1128/jmbe.v21i3.2145

Journal of Microbiology & Biology Education

COVID-19 and the Central Dogma: an Activity To Improve Student Learning and Engagement†

Carli Roush[1,2] and Alita R. Burmeister[2,3]*

[1]*Yale College, New Haven, CT 06520;*

[2]*Department of Ecology and Evolutionary Biology, Yale University, New Haven, CT 06520;*

[3]*BEACON Center for the Study of Evolution in Action, East Lansing, MI 48824*

INTRODUCTION

The Central Dogma of molecular biology describes the transfer of genetic information within organisms and is a core concept in the biological sciences. However foundational, the Central Dogma is often misrepresented when taught in introductory college biology courses. In particular, the Central Dogma is often taught with a requisite DNA step, an incorrect conception that omits the possibility of RNA-based molecular systems, such as SARS-CoV-2, the causative agent of COVID-19. In this article, we offer a practical way to clarify correct conceptions and make them immediately relevant through COVID-19. In this new digital "sorting cards" activity, students collaboratively synthesize and map their knowledge of core molecular biology. Building off of the typically presented concepts of the Central Dogma, we also introduce two sorting card expansion packs for double-stranded DNA (dsDNA) viruses and single-stranded RNA (ssRNA) viruses. We provide activity templates for all sets of cards using a free web-based collaborative platform suitable for sudden shifts to online learning (as in our implementation), preplanned online learning, and in-person classes. While truly hands-on activities can be difficult to replicate in the context of online learning, the use of collaborative websites and creative freedom in this activity encourages student engagement in and ownership of their learning.

The Central Dogma in biology education

Foundational throughout biology, the Central Dogma is often presented in introductory biology classes as a rigid rule: DNA is either replicated or transcribed into RNA, and RNA is translated into protein. However, when Francis Crick first proposed the model of the Central Dogma in 1958, he did not describe a rigid pathway. Instead, Crick posited simply that genetic information that has been transferred into proteins cannot be transferred again (1). While this hypothesis did not allow for proteins to replicate, nor to be back-translated into RNA or DNA, it did not rule out the intriguing possibilities of information transfer from RNA to RNA or from RNA to DNA—transfers now known to occur in nature. Yet soon after Crick published on this model of information transfer, the misconception of the rigid flow became so prevalent that he published a reaction in 1970 specifying and clarifying his original idea of the Central Dogma (2). However, even today, educators continue to use the oversimplified Central Dogma (3), perhaps in part because they have lacked immediately relevant examples of alternative information flow.

A new activity for learning the Central Dogma

With the recent outbreak and global pandemic of SARS-CoV-2, biology educators have also suddenly needed to facilitate learning online. This has proved especially problematic for courses with active learning, laboratory components, and course-based undergraduate research experiences (CUREs), where meaningfully engaging students over a video chat lacks the usual ease of conversation and formative feedback. With COVID-19 physical distancing in place, here we use SARS-CoV-2 as a mechanism through which to discuss the Central Dogma of molecular biology in an online environment. SARS-CoV-2 is a highly relevant example of information transfer that does not conform to the Central Dogma as it is often taught: as a positive-sense single-stranded RNA [(+)ssRNA] virus, its genetic information does not pass through a DNA stage. Instead, SARS-CoV-2 passes its information from a positive-sense mRNA genome to a negative-sense molecule and back, and this information flows into its encoded proteins.

This classroom activity is designed to engage students in deeper thinking about informational transfer and the Central Dogma as a conceptual framework with a relevant subject matter. We built this online version by adapting the DNA-

*Corresponding author. Mailing address: P.O. Box 208106, New Haven, CT 06520. E-mail: alita.burmeister@yale.edu.
Received: 11 May 2020, Accepted: 22 September 2020, Published: 12 November 2020
†Supplemental materials available at http://asmscience.org/jmbe

rooted sorting cards originally developed by Buckley and Angert (Appendix 1) into an interactive collaboration tool. We also developed online card templates and introduced two new viral expansion packs.

PROCEDURE

Before the class period, students were asked to read Crick 1970 (2) and watch two YouTube videos describing DNA and RNA virus replication while taking notes on discussion-related questions (Appendix 2).

The class period was conducted synchronously online via Zoom. Students were asked to type a question from their homework into the online chat box (in an in-person classroom context, students would each ask a question out loud), and instructors guided a discussion around these questions, encouraging students to answer their peers' questions. This discussion took approximately 20 minutes.

Instructors next introduced the Central Dogma concept–diagramming activity, explained how it relates to the homework, and gave a short demonstration of using MURAL (https://www.mural.co/), an online collaboration tool featuring easy integration of text, images, and simultaneous editing (about 10 minutes total). The demonstration involved simple tasks of how to draw, place shapes, insert images, etc. Students were split into small groups of two to three using Zoom breakout rooms. Each group received a link to their own blank MURAL template (Appendix 3) and began to work on constructing the diagrams of informational flow described in Crick 1970.

The students were directed to start with the terms in the basic set of digital sorting cards (Table 1), which describe the general processes and structures involved in cellular DNA-rooted replication, transcription, and translation. [See Buckley and Angert 2018 (Appendix 1) for instructions on using the original paper-based set during in-person classes.] This activity was designed to require collaboration; while simultaneously editing their MURAL documents, students needed to be in constant communication about designing, drawing, and discussing any concepts that they felt unsure about. As instructors, we checked in on group progress on MURAL pages and by floating among the Zoom breakout rooms, analogous to our usual activities during in-person active learning. We encouraged students to practice verbally walking through each step in the process to ensure their understanding and used these informal interactions to provide formative feedback, answer questions, and discuss misconceptions.

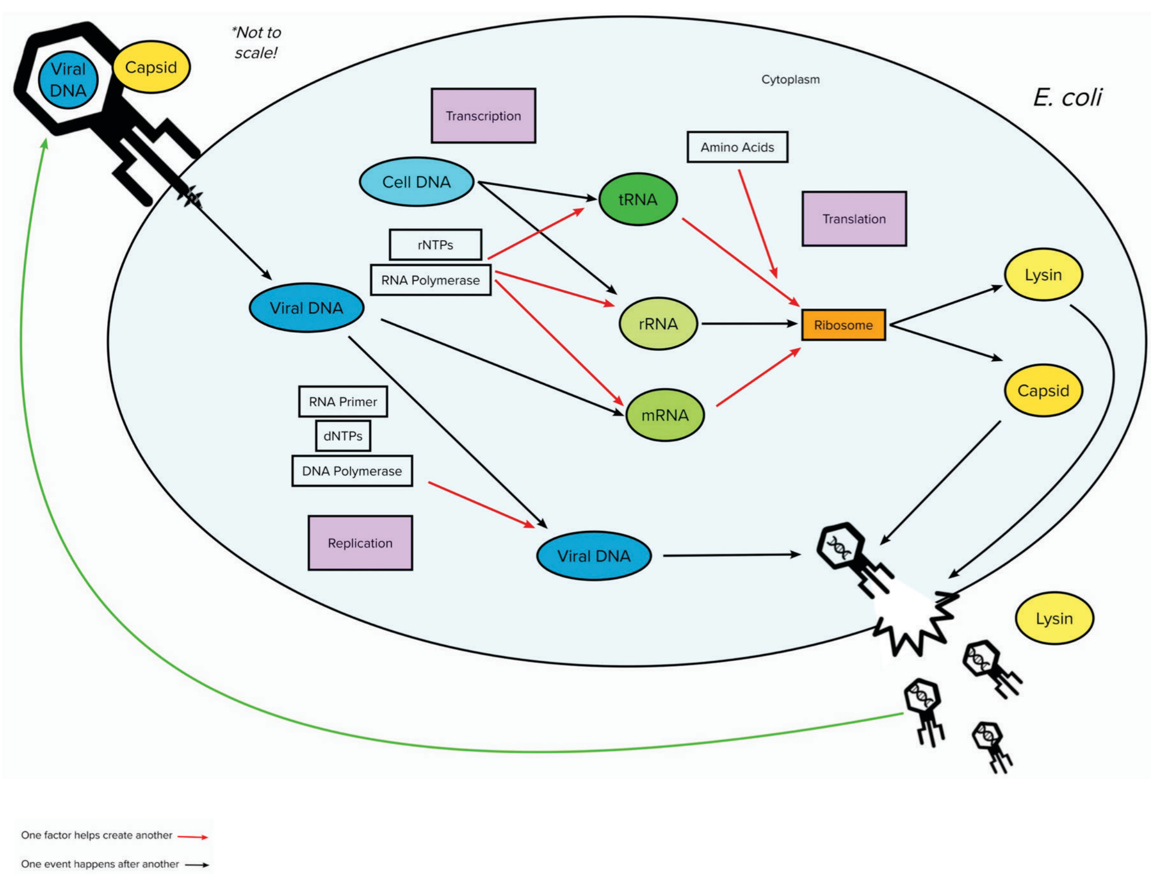

FIGURE 1. Example original student work on bacteriophage U136B using the basic and double-stranded DNA phage card packs. See Appendix 3 for the template students started with.

TABLE 1.
List of terms used in each portion of the activity.

Card Set and Terms	Activity and Sample Material		
	Basic Set	dsDNA Virus	(+)ssRNA Virus
	E. coli, *H. sapiens*	Bacteriophage U136B	SARS-CoV-2
Basic Set			
DNA	+	+	+
mRNA	+	+	+
rRNA	+	+	+
tRNA	+	+	+
DNA polymerase	+	+	+
RNA polymerase	+	+	+
Ribosome	+	+	+
dNTPs	+	+	+
rNTPs	+	+	+
RNA primer	+	+	+
Protein	+	+	+
Amino acids	+	+	+
Replication	+	+	+
Transcription	+	+	+
Translation	+	+	+
Double-Stranded DNA Virus Expansion Pack			
Capsid		+	
Lysin		+	
Viral DNA		+	
Positive-Sense Single-Stranded RNA Virus Expansion Pack			
Positive-sense RNA			+
Negative-sense RNA			+
RNA-dependent RNA polymerase			+
Envelope and nucleocapsid protein			+

Terms in the basic set are from Buckley and Angert's paper-based activity (Appendix 1).

After compiling the basic set of cards, each group moved onto integrating the terms from the dsDNA virus set into their existing diagram (Table 1, Fig. 1). In our implementation, we focused on a particular bacteriophage, U136B, that students were already familiar with through their laboratory research work and readings throughout the semester, for example, a research paper related to phage therapy (4). In other courses, the activity could focus on nearly any other lytic dsDNA virus. These basic and dsDNA virus phases together took approximately 40 minutes.

Afterwards, all students reconvened along with the instructors. Each group was assigned a small part of the process (e.g., DNA replication) to present verbally, using their diagrams as visual aids. This took approximately 10 minutes. Feedback was given formatively, using student presentations as a way to expand on ideas and correct incorrect conceptions for the entire class.

For homework, students were assigned to work in their groups to complete the positive-sense single-stranded RNA virus set of terms in the same way (Table 1, Appendix 4). Then, they used Zoom's recording feature to upload a 3- to 4-minute video presenting both visual diagrams, with each group member contributing to the presentation. The students were graded on their in-class participation and their uploaded presentations. During Spring 2020, we graded on completion, in part as an overall effort to reduce workload during the pandemic and emergency online teaching, but also because our university had implemented universal pass/fail grading. However, the activity could easily be graded for credit, in particular through the use of a rubric.

We find our process could easily be adapted to fit other formats and timeframes. For example, our total time in class was around 80 minutes, but instructors might have students instead answer prequestions, spend less time on their concept mapping, or move follow-up to another class session. Our students had committed to synchronous online meetings, but the activity could alternatively be introduced via recorded instructions, and students could arrange to work collaboratively outside of class. Our viral expansion packs could also be more simply printed as traditional sorting cards and used in person.

Finally, we want to highlight considerations for equity and inclusion that we reflected on during development of this activity. Before implementing and grading this particular online project, the instructor of record first reached out to the students to ensure they had access to reliable internet and safe learning environments. We learned that those conditions could not necessarily be met by all of our students, so we planned on extended deadlines and grading on completion rather than accuracy when establishing expectations and evaluating outcomes. Overall, this approach worked well with our small class of college students who had committed to availability for synchronous online learning and participation, even during a national emergency and with varied home learning environments.

Safety issues

None.

Adaptability

Instructors should feel free to modify the cards according to their own learning objectives. For example, some instructors may want to include organelles, so they may add "nucleus" to their SARS-CoV-2 card bank. Others may want to focus on viral cell entry and exit, so "uncoating" (the mechanism by which SARS-CoV-2 enters cells) might be added to the bank. Addition or consideration of these and other structures and processes also provides a basis for formative assessment and discussions among instructors and students. For example, Figure 2, showing an authentic student example, could be used as a discussion starting point both for the role of nuclei in DNA replication and translation and to discuss the entry of coronavirus into the cell.

This version of the activity requires internet access for the use of Zoom, YouTube, and MURAL or other online collaborative platform, such as Google Slides. For students with limited internet access, such as in rural areas, instructors may consider reworking this activity to take place asynchronously, possibly asking students to submit pictures of handwritten diagrams rather than using an online platform. There may also be concerns about the privacy and accessibility of websites like MURAL and YouTube outside of the United States. In those cases, the activity can be easily

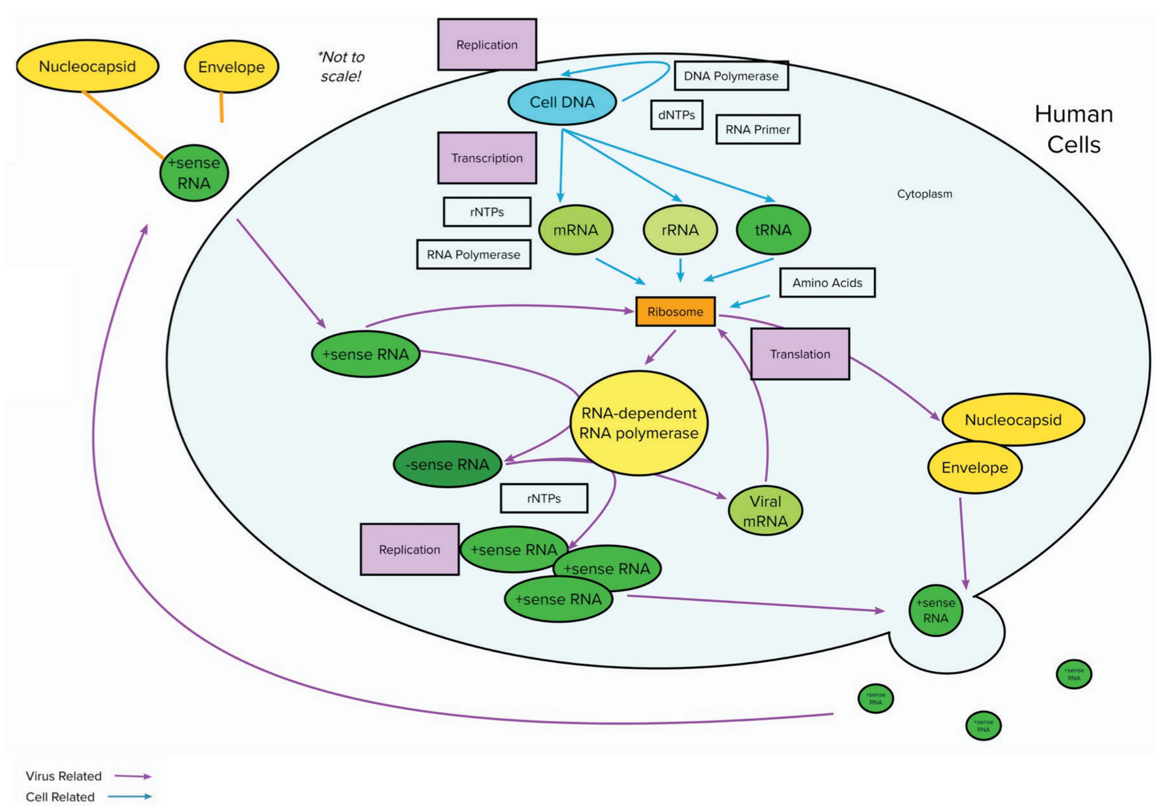

FIGURE 2. Example original student work on SARS-CoV-2 using the basic and positive-sense RNA virus card packs. See Appendix 4 for the template students started with.

adapted to utilize any other virtual whiteboard, including Google Jamboard and Google Slides. Additionally, the YouTube videos provided for background knowledge and preparation could be exchanged for readings or instructor-made videos on the same topics.

While this activity was developed within a small class setting, where discussions involving all students were viable, it could be adapted to a higher-enrollment course by instead implementing it in discussion sections.

Overall, we encourage instructors to try different formats and variations according to their learning objectives and student populations. We also welcome any instructors to contact us to talk through implementation details or for a videoconference walk-through of our set-up.

CONCLUSION

This activity was highly successful in facilitating discussion of what the Central Dogma means for biologists and in encouraging the extensive collaboration of students. Students created diagrams that integrated many aspects of replication, transcription, and translation in cells and did so uniquely and creatively. Because students in the class have different college biology coursework backgrounds, they also benefited from the collaborative, peer-learning format. Students who are more familiar with the biological concepts reinforce their knowledge, while the students without previous exposure benefit from working with somebody who can explain foreign concepts. Beyond emergency transitions to online instruction, we see this activity as one that can be used more routinely during a typical on-campus school year or in preplanned online-only courses where students have more equal access to the Web and suitable learning environments. While true "hands-on" activities are difficult to replicate in the context of online learning, the use of an online collaborative platform and the creative freedom that the students were given in designing their own conceptual diagrams served to engage students in learning and encouraged active participation.

SUPPLEMENTAL MATERIALS

Appendix 1: Original sorting cards activity, reproduced with permission by Buckley and Angert
Appendix 2: Homework prompts
Appendix 3: MURAL template for basic pack and dsDNA virus expansion pack
Appendix 4: MURAL template for positive-sense RNA virus expansion pack

ACKNOWLEDGMENTS

We thank the students of EEB175L for their work and active participation in this classroom activity. We thank Mike Blazanin and Caroline Turner for useful comments on the manuscript. We are grateful to Daniel Buckley and Esther Angert for allowing their original activity to be published in full as Appendix 1 of this article. Our work was supported by the Howard Hughes Medical Institute Grant Campus Grant #52008128. The authors have no conflicts of interest to declare.

REFERENCES

1. Crick FH. 1958. On protein synthesis. Symp Soc Exp Biol 12:138–163.
2. Crick F. 1970. Central dogma of molecular biology. Nature 227:561–563.
3. Blazanin M, Burmeister AR. 2020. An idea to explore: revisiting the central dogma 60 years later to improve student learning. In review.
4. Burmeister AR, Fortier A, Roush C, Lessing AJ, Bender RG, Barahman R, Grant R, Chan BK, Turner PE. 2020. Pleiotropy complicates a trade-off between phage resistance and antibiotic resistance. Proc Natl Acad Sci USA 117:11207–11216.